

19

3. Provide a gas-tight seal between each of the interior of the liner, the environment of the annular heating member, and the exterior of the apparatus;

4. Evacuate the interior of the liner and the environment of the annular heating member;

5. Fill a predetermined fraction of the interior of the liner with a solvent through a fill-pipe or fill-tube and seal the fill-pipe or fill-tube;

6. Fill the environment of the annular heating member with a predetermined pressure of an inert gas;

7. Process the liner with thermal energy to cause an increase in temperature within the liner to greater than 200 Degrees Celsius to cause the solvent to be superheated;

8. Form a crystalline material from a process of the superheated solvent;

9. Remove thermal energy from the liner to cause a temperature of the liner to change from a first temperature to a second temperature, which is lower than the first temperature;

10. Remove solvent through a fill-pipe or fill-tube;

11. Open the top portion of the apparatus, exposing the interior of the liner;

12. Remove the crystalline material; and

13. Perform other steps, as desired.

FIG. 6 is a simplified flow diagram 600 of an alternative method of processing a material within a supercritical fluid according to an alternative embodiment of the present invention. The method begins with start, at step 601. Then an assembling step 603 is performed. In a specific embodiment, the apparatus has a cylindrical capsule region comprising a first region and a second region, and a length defined between the first region and the second region. The apparatus also has an annular heating member enclosing the cylindrical capsule region and at least one continuous ceramic or annular metal or cermet member having a predetermined thickness disposed continuously around a perimeter of the annular heating member, which are assembled together, step 605. In a specific embodiment, the capsule, heating member, and annular member are inserted into a high strength enclosure material disposed overlying the annular ceramic member.

The method provides a capsule containing a solvent, such as ammonia, for example, which includes a material to be processed, step 607. The capsule is sealed at step 609. Each of the capsule ends are welded and/or brazed to form a sealed capsule structure. The method assembles by placing (step 611) the capsule containing the solvent and starting crystal within an interior region of the cylindrical capsule region. Annular plugs, end caps, and end flanges are placed on to each of the ends of the apparatus, step 613. See, for example, FIG. 2. In a preferred embodiment, each of the end flanges is secured by a fastener or a plurality of fasteners.

Electrical energy (step 617) is then provided to the heating member. The heating member provides thermal energy to the capsule to a predetermined process temperature and pressure, which cause the solvent to be in a supercritical state, by raising the temperature within the capsule to greater than 200 degrees Celsius to cause the solvent to be superheated.

A crystalline material, e.g. gallium containing crystal such as GaN, AlGaN, InGaN forms from the superheated solvent. The capsule is cooled from a first temperature to a second temperature. Once the energy has been removed and temperature reduced to a suitable level, the flanges, which mechanically held at least the capsule in place, are removed. A mechanical member, such as a plunger, hydraulically moves the mechanical member from the first region of the cylindrical capsule region toward the second region to transfer the cap-

20

sule out of the cylindrical capsule region free from the apparatus. The capsule is then opened and the crystalline material removed.

In some embodiments, the apparatus is used to grow bulk gallium-containing nitride boules, as described in U.S. Patent Application No. 2010/0031875, which is hereby incorporated by reference in its entirety for all purposes. The bulk gallium-containing nitride boules may be sliced into one or wafers by sawing, lapping, polishing, chemical-mechanical polishing, and/or by other methods that are known in the art. The gallium-containing crystal wafers may be used as substrates to form optoelectronic or electronic devices such as: a light emitting diode, a laser diode, a photodetector, an avalanche photodiode, a transistor, a rectifier, and a thyristor; one of a transistor, a rectifier, a Schottky rectifier, a thyristor, a p-i-n diode, a metal-semiconductor-metal diode, high-electron mobility transistor, a metal semiconductor field effect transistor, a metal oxide field effect transistor, a power metal oxide semiconductor field effect transistor, a power metal insulator semiconductor field effect transistor, a bipolar junction transistor, a metal insulator field effect transistor, a heterojunction bipolar transistor, a power insulated gate bipolar transistor, a power vertical junction field effect transistor, a cascode switch, an inner sub-band emitter, a quantum well infrared photodetector, a quantum dot infrared photodetector, a solar cell, and a diode for photoelectrochemical water splitting and hydrogen generation.

While the above is a full description of the specific embodiments, various modifications, alternative constructions and equivalents may be used. Therefore, the above description and illustrations should not be taken as limiting the scope of the present invention which is defined by the appended claims.

What is claimed is:

1. Apparatus for high pressure material processing, the apparatus comprising:

a cylindrical capsule region including a first region and a second region, having a length between the first region and the second region;

a heating member enclosing the cylindrical capsule region; a sleeve member adapted to form a sealed region enclosing the heating member, the sealed region being characterized by an internal pressure level capable of tightening a contact between the sleeve member and a seal;

a gas pressure intensifier for pumping gaseous species into the sealed region at a predetermined range of pressure levels;

at least one annular ceramic member having a predetermined thickness disposed continuously around a perimeter of the sleeve member, the annular member being made of a material having a compressive strength of at least 0.5 GPa and having a thermal conductivity of less than about 4 watts per meter-Kelvin; and

a high strength enclosure material over the annular ceramic member to form a high strength enclosure.

2. The apparatus of claim 1 further comprising a control module to control an amount of a gaseous species to be pumped into the sealed region by the gas pressure intensifier based.

3. The apparatus of claim 1 further comprising a temperature sensor positioned within the heating member in proximity to the cylindrical capsule region.

4. The apparatus of claim 1 wherein the gaseous species comprises an inert gas.

5. The apparatus of claim 1 further comprising a displacement sensor positioned within the heating member in proximity to the cylindrical capsule region.